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Structural Optimization of an Innovative 10 MW Wind Turbine Nacelle

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Abstract

For large wind turbine configurations of 10 MW and higher capacities, direct-drives present a more compact solution over conventional geared drivetrains. Further, if the generator is placed in front of the wind turbine rotor, a compact "king-pin" drive is designed, that allows the generator to be directly coupled to the hub. In presented study, the structural re-design of the 10 MW king-pin drive and nacelle was made using extreme loads obtained from a 10 MW reference wind turbine. On the basis of extreme loads the ultimate stresses of critical components were determined to ensure integrity of the structure. Farther, the tower top mass was reduced on the basis of the topology optimization results with compliance limits applied for the mainframe. Presented analysis shows that a structural mass of the nacelle components can be reduced without significant influence on the mechanical properties of the structure. The total weight of the nacelle after mass reduction is 24 % lower than for the initial design.

Objective and Methodology

In the study the design concept of direct-drive **10 MW offshore wind turbine** with a 178 m rotor diameter and three blades was analyzed [1 - 3].

- **Objective - to reduce tower top mass for floating offshore wind turbines**
- **Methodology** – application of **topology optimization** algorithms on a predefined design domain for the **chosen nacelle component**
- **Assumptions** – the **parameters of bolted connections** and **yaw mechanism** in topology optimization study **were neglected**. Nacelle components made from **ductile cast iron** EN-GJS-400 with design strength of **246 MPa**.

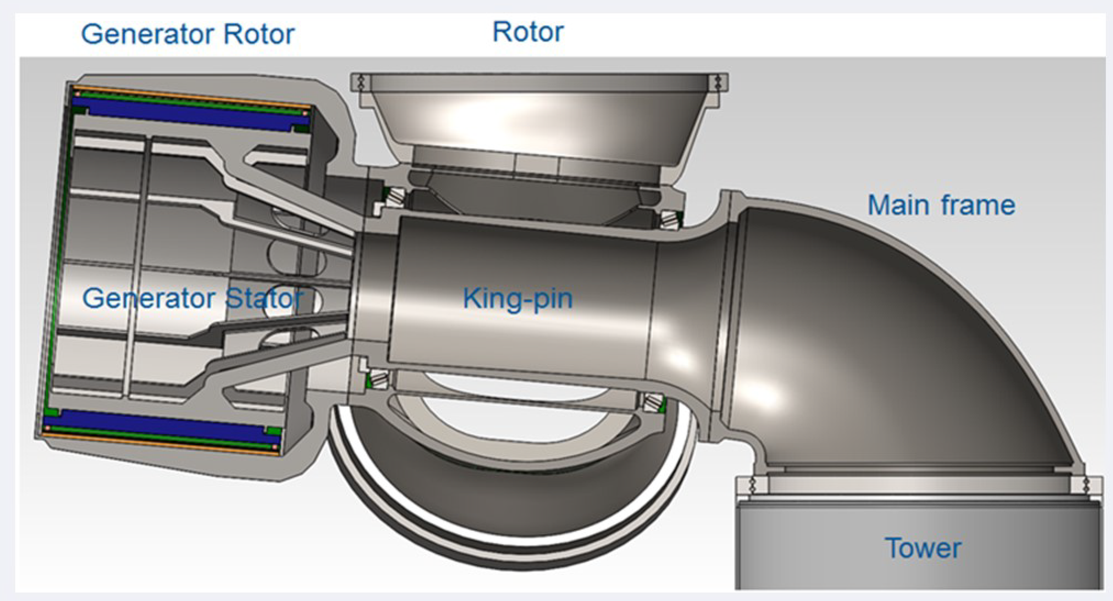

Figure 1: King-pin nacelle layout for 10 MW offshore wind turbine

Table 1 Extreme loads in 10 MW reference turbine

	Initial design
Tower top fore-aft moment	18300 kNm
Thrust force	4600 kN
Torsional moment	16500 kNm
Tower top side-side moment	10000 kNm

On the basis of HAWC2 [4] simulations for 10 MW DTU reference wind turbine [1] (DLC 1.3 from IEC 61400-1)

Organization of the study:

The initial design of 10 MW offshore wind turbine

FE model , extreme loads

Verification of the integrity of a structure (king-pin connected to mainframe) **means for a mass reduction**

Topology optimization

The optimal topology of the mainframe under ultimate loads

Correction of geometry to avoid low local stiffness in flanges and yaw bearing

The final geometry meeting the design constraints

FE model , extreme loads

Verified design

Structural Optimization

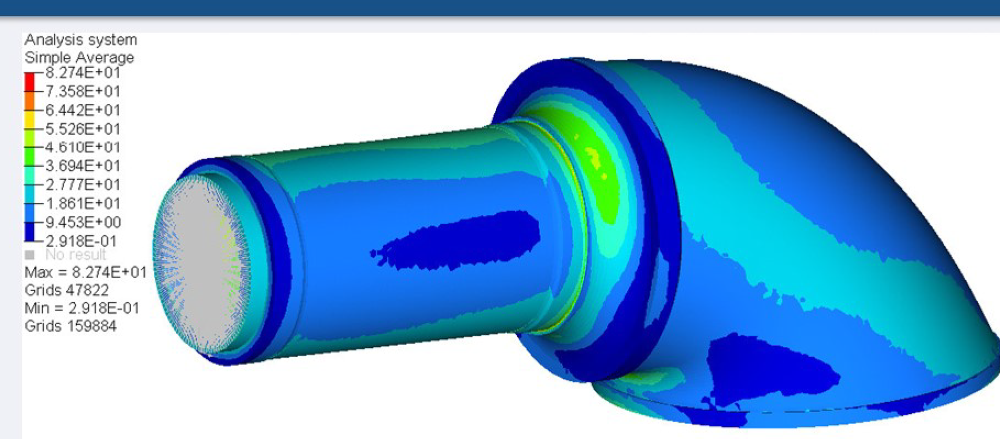

Figure 2: **Initial design** - von Mises stress distributions in king-pin and mainframe for extreme loads [MPa]

Finite Element model:

- the king-pin connected to the mainframe constrained on the bottom part
- 3D elements, Hypermesh [5] and Optistruct solver [6]

Topology optimization:

- **design area** – the mainframe between the flange and yaw bearing,
- **design variable** - density of the finite elements,
- **objective** - to minimize material volume of the design area,
- **constraint** – compliance of the structure.

In the study analyzed topology optimization cases with different compliance limits and load sets. Compliance limits set on the nodes located on the surface connecting the king-pin with generator.

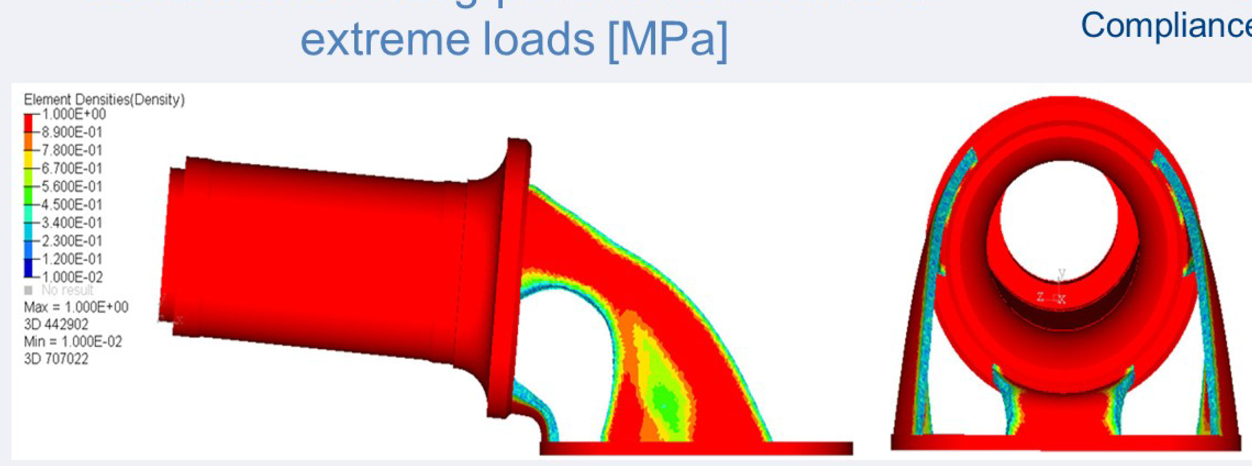

Figure 3: Topology optimization case with fore-aft, torsional moment and thrust force (disp. const. 20 mm, elem. dens. > 0.3)

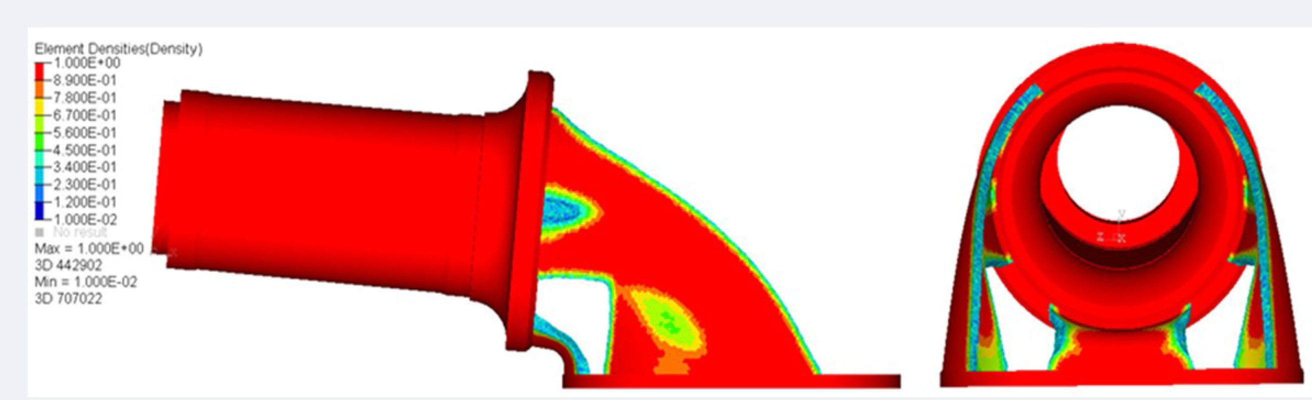

Figure 4: Topology optimization case with fore-aft, side-side, torsional moment and thrust force (disp. const. 20 mm, elem. dens. > 0.3)

Results

To increase stiffness in the bolted connection between the king-pin and mainframe and to provide an uniform load distribution on the yaw bearing, additional material was added to the optimal design presented in figure 3 and 4. Beside of the structural modifications of the mainframe, additionally mass from the king-pin was reduced by decreasing thickness of the cylinder wall about 20 %, that connects the upwind and downwind bearings.

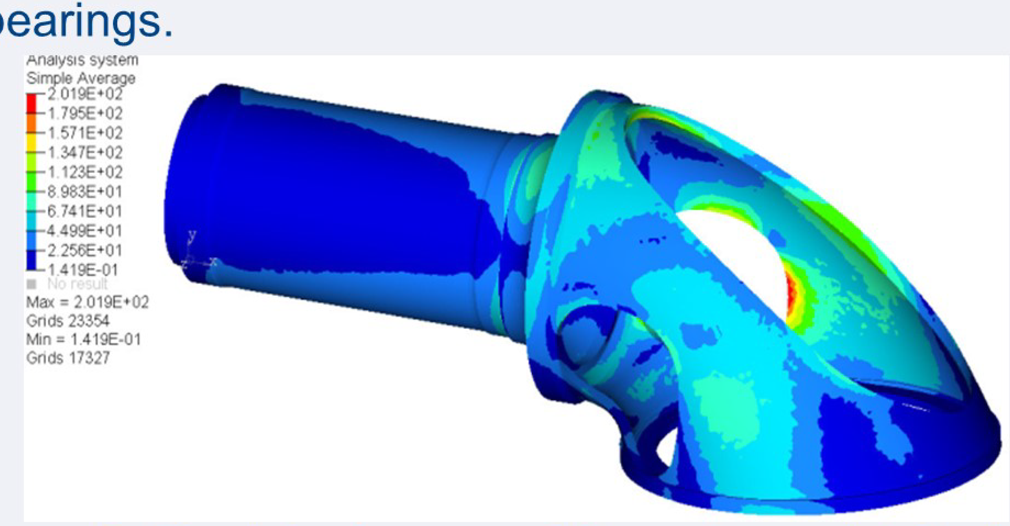

Figure 5: **Final design** - von Mises stress distributions in king-pin and mainframe for extreme loads [MPa]

Table 2 Mass reduction summary

	Initial design	Final design
King-pin mass	57,043 kg	49,927 kg
Mainframe mass	65,176 kg	43,084 kg
Total mass	122,219 kg	93,011 kg
King-pin mass reduction	-	12.5 %
Mainframe mass reduction	-	33.9 %
Total mass reduction	-	23.9 %

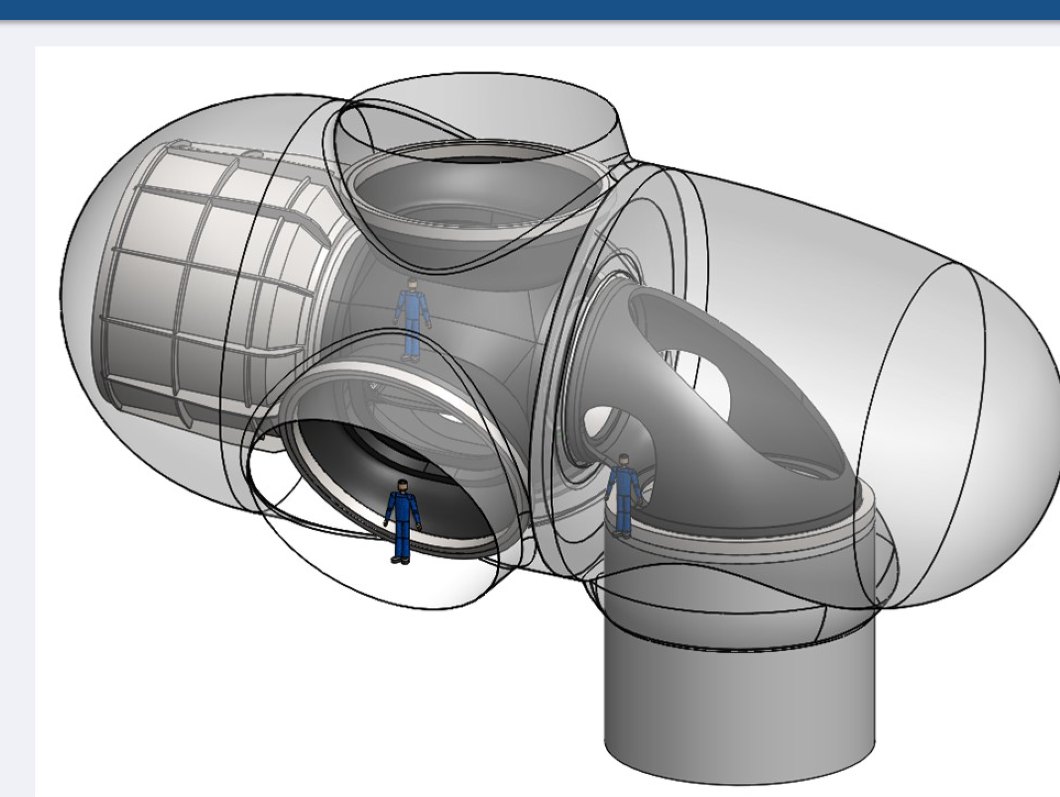

Figure 6: Concept design of 10 MW direct-drive wind turbine after mass reduction

Conclusions

The total mass reduction of the nacelle for the concept design of 10 MW offshore wind turbine was obtained as **24 %** lower than the initial concept. The topology modifications do not affect the integrity of the structure as verified on the basis of ultimate stresses. The negative influence of geometry modifications on the bolted connections and yaw bearing was corrected by increasing the material density around these areas. Proposed design of the mainframe can be improved in terms of its stiffness e.g. by including stiffeners and ribs.

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